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Feasibility and Preliminary Clinical Responses to Immersive Virtual Reality in Adults with Self-Reported Bruxism-Related Orofacial Pain: A Pilot Longitudinal Study

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Abstract

Bruxism-related orofacial pain is a common clinical manifestation associated with muscular hyperactivity, psychoemotional factors, and altered pain sensitivity. Immersive virtual reality (iVR) has emerged as a non-pharmacological strategy for pain management; however, evidence in individuals with bruxism-related pain remains limited. This pilot study evaluated the feasibility, tolerability, and preliminary clinical responses associated with an iVR intervention in adults with bruxism-related orofacial pain. A longitudinal pilot study with repeated assessments (T0–T4) was conducted in 15 adults with self-reported bruxism-related orofacial pain. Participants completed two standardized relaxation-oriented iVR sessions using an Oculus Quest 3 head-mounted display. Feasibility, immersive experience, cybersickness symptoms, pain intensity, and pressure pain threshold (PPT) were evaluated. All participants completed the intervention protocol and follow-up assessments, resulting in 100% adherence. Cybersickness symptoms were mild, and immersive experience scores indicated high perceived presence. Pain intensity decreased progressively throughout follow-up, with the greatest reduction observed at T4. The pressure pain threshold demonstrated modest temporal increases, particularly in the splenius, upper trapezius, and temporalis regions. The intervention was feasible and well tolerated and was accompanied by exploratory reductions in pain-related outcomes over time. These findings support future controlled studies to clarify the clinical effects of immersive virtual reality in individuals with bruxism-related orofacial pain.

Keywords: immersive virtual reality; bruxism; orofacial pain; pressure pain threshold; feasibility

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1. Introduction

Bruxism is a repetitive activity of the masticatory muscles characterized by clenching or grinding of the teeth during wakefulness or sleep [1]. It is currently considered a multifactorial condition involving the interaction of biomechanical, neurophysiological, and psychoemotional factors, including stress, anxiety, sleep disturbances, and altered pain modulation mechanisms [2]. Its prevalence in adults has been estimated between 22% and 30% [3], making it a frequent condition within the spectrum of temporomandibular disorders and orofacial pain [4].

One of the main clinical consequences of bruxism is persistent orofacial pain, frequently accompanied by muscular tension, mandibular functional impairment, and reductions in the pressure pain threshold (PPT) [5]. In many individuals, pain may interfere with essential daily activities such as chewing, speaking, sleeping, and social interaction [6]. Previous evidence has also suggested that bruxism-related pain involves both peripheral and central nociceptive mechanisms, together with psychoemotional factors capable of amplifying symptom perception and persistence over time [7].

Conventional therapeutic approaches for bruxism include occlusal splints, pharmacological management, and behavioral strategies focused on stress reduction and habit control [8]. However, these interventions present important limitations. Occlusal splints require prolonged adherence and periodic follow-up, pharmacological treatments may generate adverse effects or limited long-term applicability, and behavioral interventions depend heavily on sustained patient engagement [9,10]. As a result, clinical responses are often heterogeneous [10], particularly in individuals with persistent pain and elevated psychoemotional burden [11,12].

In recent years, immersive virtual reality (iVR) has been increasingly explored as a non-pharmacological intervention for pain management and rehabilitation [13,14]. By redirecting attention away from painful stimuli and promoting relaxation, iVR may help modulate pain perception [15,16]. Although beneficial effects have been reported in several chronic pain conditions, evidence in craniomandibular and orofacial pain disorders remains limited, particularly in patients with bruxism-related symptoms [17].

Given the close interaction between muscular tension, stress, and pain sensitivity in bruxism [18], relaxation-oriented immersive environments could represent a relevant therapeutic approach. Visual and auditory immersive stimuli may facilitate relaxation and temporarily reduce pain-related awareness [19].

However, the feasibility, tolerability, and potential clinical effects of iVR interventions in individuals with bruxism-related orofacial pain remain unclear. Pilot studies are therefore needed before conducting larger controlled trials.

Accordingly, this pilot longitudinal study aimed to evaluate the feasibility and tolerability of an immersive virtual reality protocol in adults with self-reported bruxism-related orofacial pain while preliminarily exploring changes in pain intensity and pressure pain sensitivity over time. Feasibility outcomes included intervention adherence, immersive experience, and cybersickness symptoms, whereas pain intensity and the pressure pain threshold were evaluated as exploratory clinical outcomes to inform the design of future controlled trials. The remainder of this manuscript is organized as follows. Section 2 describes the study design, participants, intervention, outcome measures, and statistical analysis. Section 3 presents the study results. Section 4 discusses the main findings in the context of the existing literature, acknowledges the study limitations, and outlines implications for future research. Finally, Section 5 summarizes the main conclusions.

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2. Materials and Methods

2.1. Design and Subjects

A longitudinal pilot feasibility study with a repeated-measures pre–post design was conducted to evaluate the feasibility, tolerability, and preliminary clinical responses associated with an immersive virtual reality (iVR) intervention in adults with bruxism-related orofacial pain. Repeated assessments were performed across five time points (T0–T4) to explore immediate, short-term, and follow-up responses following two iVR sessions. This pilot design was selected because feasibility studies are considered appropriate during early phases of clinical research to assess implementation procedures, participant tolerability, user experience, safety, and the suitability of selected outcome measures before conducting larger randomized controlled trials.

A convenience sample of 15 adults aged between 18 and 60 years with bruxism-related orofacial pain participated in the study. Given the exploratory nature of this pilot feasibility study, a formal a priori sample size calculation was not performed. The selected sample size was considered appropriate to evaluate feasibility, intervention tolerability, usability, implementation procedures, and preliminary clinical responses, consistent with methodological recommendations for pilot studies.

Participants were recruited through advertisements distributed within university and clinical settings. Individuals interested in participating completed the *Cuestionario Autoreportado de Bruxismo* (CAB; Self-Reported Bruxism Questionnaire) [20], which was used as an initial screening tool to identify adults with self-reported bruxism-related symptoms associated with orofacial pain. According to the CAB scoring system, total scores of 16–30 indicate possible–mild bruxism, 31–45 probable–moderate bruxism, whereas scores of 0–15 and $\geq$46 correspond to improbable and severe bruxism, respectively. Only participants classified as possible–mild or probable–moderate bruxism were eligible for inclusion. Consistent with the international consensus on bruxism assessment, self-reported symptoms were considered indicative of possible bruxism and were not intended to establish a definitive diagnosis, which requires clinical examination and/or instrumental confirmation [21]. Inclusion criteria were: (a) age $\geq$ 18 years; (b) self-reported orofacial pain associated with bruxism; (c) pain intensity $\geq$ 3/10 on the Numeric Rating Scale (NRS) during the previous week; and (d) ability to understand and interact with immersive virtual reality technology. Exclusion criteria included: (a) history of maxillofacial surgery within the previous 6 months; (b) diagnosed neurological or vestibular disorders; (c) use of centrally acting analgesics or muscle relaxants within 48 h prior to participation; and (d) history of severe intolerance or adverse reactions related to virtual reality exposure. Participants were additionally instructed to avoid analgesic or muscle relaxant intake during the evaluation period whenever possible, unless medically necessary.

The study was conducted in accordance with the principles of the Declaration of Helsinki [22] and was approved by the Ethics, Bioethics, and Scientific Integrity Committee of the Escuela Colombiana de Rehabilitación (ECR), Bogotá, Colombia (approval code: ECR-CI-INV-050-2025; approval date: 4 November 2025). All participants provided written informed consent prior to participation. The ethics-approved protocol prospectively included the complete intervention schedule and follow-up assessments reported in this manuscript, including two immersive virtual reality sessions and evaluations at T0, T1, T2 (48 h), T3, and T4 (48 h). Therefore, no protocol amendments were required after ethics approval.

The study was conducted in a quiet, temperature-controlled environment to minimize external influences on sensory and pain responses. Participants attended two immersive virtual reality sessions separated by 48 h. The evaluation protocol consisted of five repeated assessments: T0 (baseline, immediately before Session 1), T1 (immediately after Session 1),

T2 (48 h after Session 1 and immediately before Session 2), T3 (immediately after Session 2), and T4 (48 h after Session 2). Thus, the interval between Session 1 and Session 2, as well as between T1 and T2, was 48 h (Figure 1). Because scheduling depended on participant availability, assessments were not standardized according to the time of day. All outcome assessments were performed in a standardized seated position by the same trained evaluator to minimize inter-rater variability, whereas the immersive virtual reality sessions were supervised and administered by a different member of the research team. The timing of all outcome assessments is summarized in Figure 1.

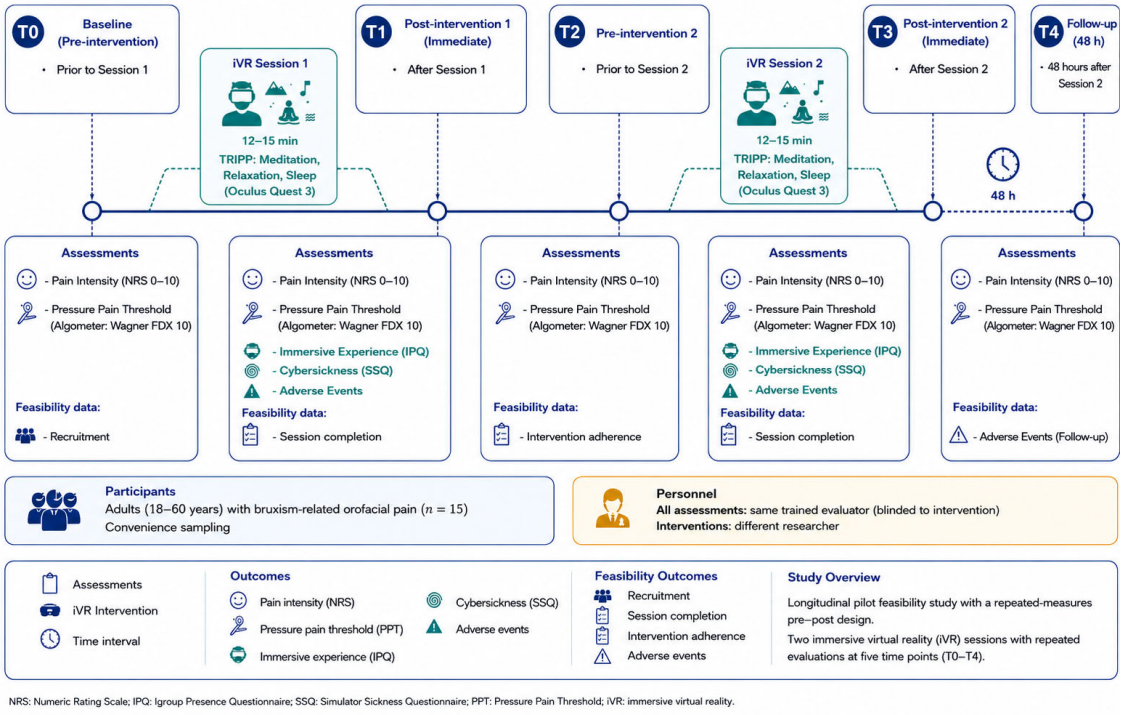


Figure 1. Timeline of the pilot longitudinal study, including immersive virtual reality intervention sessions and repeated assessments across T0–T4.

2.2. Intervention

Participants completed two standardized immersive virtual reality sessions using an Oculus Quest 3 head-mounted display (HMD) (Meta Platforms Inc., Menlo Park, CA, USA). Each session lasted approximately 20 min, corresponding to the predefined duration of the commercially available *Focus* module, which was delivered without interruption or modification by the research team. The sessions were delivered using the commercially available TRIPP® application (Meditation, Relaxation, Sleep, version 5.3.12.6504), which provides immersive meditation, relaxation, and sleep-oriented experiences through mindfulness exercises, guided breathing, immersive nature-based environments, relaxing background music, body-awareness exercises, and audiovisual stimulation [23,24]. The application was not developed specifically for this study. Instead, the commercially available *Focus* module within the TRIPP® application was selected because its guided breathing, mindfulness exercises, immersive audiovisual environment, and attentional focus activities were considered appropriate for the study objectives. The same *Focus* module was used during both intervention sessions for all participants, following the application's predefined sequence without modification of its original audiovisual content or guided activities.

Before each intervention, participants completed a brief familiarization with the Oculus Quest 3 interface by freely navigating the headset's main virtual environment to ensure comfortable interaction with the device. The headset was individually adjusted before

each session to maximize visual comfort and minimize the risk of cybersickness. Subsequently, standardized instructions regarding the intervention procedure were provided. During the immersive experience, participants remained seated while following the guided breathing, mindfulness, and body-awareness activities integrated within the application. They were instructed to visually explore the immersive virtual environment and perform slow, controlled head and cervical movements in response to the interactive visual stimuli presented within the application. Each session was supervised by the same member of the research team through real-time screen casting, allowing continuous monitoring, technical assistance when required, and standardized intervention delivery without interfering with the immersive experience.

2.3. Assessment of Outcomes

Primary outcomes of this pilot feasibility study were feasibility, immersive experience, intervention tolerability, and adverse events associated with immersive virtual reality exposure. Secondary outcomes included pain intensity and the pressure pain threshold (PPT). Pain intensity and PPT were assessed at all five evaluation time points (T0–T4). Immersive experience was evaluated using the Igroup Presence Questionnaire (IPQ), and cybersickness symptoms were assessed using the Simulator Sickness Questionnaire (SSQ), both administered immediately after each immersive virtual reality session (T1 and T3). Feasibility indicators (recruitment, intervention adherence, and completion of scheduled assessments) and adverse events were monitored throughout the study period.

2.3.1. Immersive Experience

Participant experience and immersive perception were assessed using the Igroup Presence Questionnaire (IPQ), a self-report instrument designed to evaluate the subjective sense of presence within virtual environments [25,26]. The questionnaire assesses dimensions related to spatial presence, involvement, experienced realism, and general presence. Higher scores indicate greater immersive experience and perceived engagement within the virtual environment. The IPQ was administered immediately after each immersive virtual reality session (T1 and T3) to evaluate participants' perceived presence following exposure to the intervention.

2.3.2. Cybersickness and Tolerability

Intervention tolerability and cybersickness symptoms were evaluated using the Simulator Sickness Questionnaire (SSQ), a standardized self-report instrument commonly used in immersive virtual reality research [27,28]. The SSQ evaluates symptoms including dizziness, nausea, headache, visual discomfort, oculomotor symptoms, and general discomfort associated with virtual reality exposure. For descriptive purposes in this pilot feasibility study, SSQ results were calculated as the raw sum of reported symptom scores, with higher scores indicating greater symptom severity and lower intervention tolerability. The SSQ was administered immediately after each immersive virtual reality session (T1 and T3).

2.3.3. Adverse Events

Adverse events associated with immersive virtual reality exposure were monitored throughout both intervention sessions and the follow-up period. Immediately after each intervention session and during the final follow-up assessment (T4), participants were actively questioned regarding the occurrence of dizziness, nausea, headache, visual fatigue, cervical discomfort, disorientation, or any other unexpected symptom experienced during or after the intervention. All adverse events were documented descriptively according to symptom type, frequency, and perceived intensity to evaluate the overall safety and tolerability of the intervention protocol.

2.3.4. Pain Intensity

Pain intensity was assessed using an 11-point Numeric Rating Scale (NRS), ranging from 0 ("no pain") to 10 ("worst imaginable pain"). Participants were asked to rate their current orofacial pain intensity at each assessment time point (T0–T4). The NRS is widely used in clinical pain research because of its simplicity, validity, reliability, and responsiveness to changes in pain intensity [29].

2.3.5. Pressure Pain Threshold

The pressure pain threshold (PPT) was assessed using a digital algometer (FDX 10; Wagner Instruments, Greenwich, CT, USA) and expressed in kg/cm^2 [30]. Measurements were obtained bilaterally over the masseter, temporalis, splenius, and upper trapezius muscles following a standardized assessment protocol. Pressure was applied perpendicularly at a constant rate until participants reported the transition from pressure sensation to pain perception. Three measurements were obtained at each anatomical site with 30 s intervals between trials, and the mean value was used for statistical analysis. Higher PPT values indicate lower pressure pain sensitivity [31].

2.4. Statistical Analysis

Continuous variables are presented as mean ± standard deviation (SD) or median and interquartile range (IQR), as appropriate, whereas categorical variables are presented as frequencies and percentages. Longitudinal changes in pain intensity and the pressure pain threshold across assessments (T0–T4) were analyzed using repeated-measures analysis of variance (ANOVA), with time included as the within-subject factor. Sphericity was assessed using Mauchly's test, and Greenhouse–Geisser corrections were applied when this assumption was violated. When a significant overall effect of time was identified, pairwise comparisons were performed using paired-samples *t*-tests with Holm adjustment for multiple comparisons. Effect sizes for the overall time effects were estimated using partial eta squared (ηp^2). Because this was a pilot feasibility study, inferential analyses were considered exploratory and hypothesis-generating rather than confirmatory. All statistical analyses were performed using JASP software (version 0.19.3; JASP Team, Amsterdam, The Netherlands). Statistical significance was established at a two-sided p-value < 0.05.

3. Results

3.1. Participant Characteristics

A total of 15 participants completed the study protocol, with no dropouts observed during the intervention sessions or follow-up assessments, resulting in a 100% completion rate. The sample consisted predominantly of women (n = 14; 93.3%), with one male participant (n = 1; 6.7%). The mean age of participants was 36.4 ± 11.5 years, with a median age of 37 years (Q1–Q3: 27.0–39.5) and a range of 21–59 years. Baseline CAB scores averaged 24.7 ± 6.7 points, with a median of 25 (Q1–Q3: 20.0–28.5) and a range of 16–39 points. Complete participant characteristics are presented in Table 1.

Table 1. Sociodemographic characteristics of the sample.

General	Mean
Age (years)	36.4 ± 11.5
Women, *n* (%)	14 (93.3)
Men, *n* (%)	1 (6.7)

Table 1. *Cont.*

General	Mean
Occupational Status	***n* (%)**
Employed	12 (80.0)
Students	3 (20.0)
Physical Activity Level	***n* (%)**
Sedentary	6 (40.0)
Lightly active	6 (40.0)
Moderately active	2 (13.3)
Vigorously active	1 (6.7)
CAB Classification	***n* (%)**
Possible–mild bruxism	13 (86.7)
Probable–moderate bruxism	2 (13.3)
Clinical Characteristics	***n* (%)**
Participants reporting comorbidities	2 (13.3)
Participants using medication	2 (13.3)

Abbreviations: SD = standard deviation; CAB = Self-Reported Bruxism Questionnaire. Values are presented as mean ± standard deviation or *n* (%). No participants were classified as improbable or severe bruxism according to CAB categorization.

3.2. Feasibility and Safety

The immersive virtual reality intervention demonstrated high feasibility. All participants completed both intervention sessions and all scheduled assessments (T0–T4), resulting in 100% adherence. No participant discontinued the intervention, and no serious adverse events associated with immersive virtual reality exposure were reported.

Reported adverse symptoms were mild and transient. The SSQ total score was 2.33 ± 2.38 points, with a median of 1.0 (Q1–Q3: 0.5–5.0) and a range of 0–7 points. Eleven participants (73.3%) reported at least one mild symptom following immersive virtual reality exposure. Feasibility and safety outcomes are summarized in Table 2.

Table 2. Feasibility and safety outcomes.

Outcome	Value
Intervention adherence, %	100
Completion of all assessments (T0–T4), *n* (%)	15 (100)
Intervention discontinuation, *n* (%)	0 (0)
Serious adverse events, *n* (%)	0 (0)
Participants reporting mild adverse symptoms, *n* (%)	11 (73.3)
SSQ total score, mean ± SD	2.33 ± 2.38
SSQ total score, median (Q1–Q3)	1 (0.5–5.0)
SSQ total score, min–max	0–7

Abbreviations: iVR = immersive virtual reality; SSQ = Simulator Sickness Questionnaire; SD = standard deviation; Q1–Q3 = interquartile range. Values are presented as mean ± standard deviation or *n* (%).

3.3. Immersive Experience and Tolerability

Participants reported a positive immersive experience following the immersive virtual reality intervention. The total IPQ score demonstrated a mean of 68.3 ± 3.0 points and a median of 69 (Q1–Q3: 66.0–70.5), ranging from 63 to 73 points, indicating high and relatively homogeneous levels of perceived presence within the virtual environment.

Among the IPQ subscales, spatial presence demonstrated the most concentrated scores (19.9 ± 1.1), followed by involvement (21.6 ± 1.5) and general presence (15.3 ± 2.0). In contrast, the realism dimension demonstrated greater interindividual variability (11.5 ± 1.7; range 9–15), suggesting subjective differences in the perception of realism within the immersive experience. Considering the IPQ and SSQ findings together, the intervention demonstrated high levels of perceived presence accompanied by low levels of cybersickness-related symptoms. Complete immersive experience outcomes are presented in Table 3.

Table 3. Immersive experience outcomes.

Outcome	Mean ± SD
IPQ total score	68.3 ± 3.0
Spatial presence	19.9 ± 1.1
Involvement	21.6 ± 1.5
Experienced realism	11.5 ± 1.7
General presence	15.3 ± 2.0

Abbreviations: IPQ = Igroup Presence Questionnaire; SD = standard deviation; Q1–Q3 = interquartile range. Values are presented as mean ± standard deviation. Additional descriptive values for the IPQ total score were median = 69 (Q1–Q3: 66.0–70.5) and range = 63–73.

3.4. Pain Intensity

Pain intensity changed over time across the five repeated assessments (T0–T4). Mean pain intensity was 5.27 ± 1.28 at baseline (T0), remained similar immediately after the first intervention (T1: 5.40 ± 0.91), and progressively decreased during subsequent assessments, reaching 3.60 ± 1.12 at the final follow-up assessment (T4). Repeated-measures ANOVA demonstrated a significant effect of time on pain intensity (F (4,56) = 10.84; $p < 0.001$; $\eta p^2 = 0.44$), indicating temporal changes throughout the study period. Holm-adjusted pairwise comparisons identified significantly lower pain intensity at T4 compared with T0 (adjusted $p = 0.003$), T1 (adjusted $p < 0.001$), T2 (adjusted $p = 0.016$), and T3 (adjusted $p = 0.003$). No other pairwise comparisons remained statistically significant after Holm adjustment. Detailed descriptive data and repeated-measures ANOVA results are presented in Table 4, whereas temporal trajectories are illustrated in Figure 2.

Table 4. Pain intensity across repeated assessments.

Time Point	Mean ± SD
T0 (baseline)	5.27 ± 1.28
T1 (post-session 1)	5.40 ± 0.91
T2 (pre-session 2)	4.73 ± 1.22
T3 (post-session 2)	4.47 ± 1.19
T4 (48 h follow-up)	3.60 ± 1.12
Repeated-measures ANOVA: F = 10.84; $p < 0.001$; $\eta p^2 = 0.44$.	

Abbreviations: SD, standard deviation; ηp^2, partial eta squared. **Note:** Data are presented as mean ± standard deviation. Pain intensity was assessed using the Numeric Rating Scale (NRS). T0 = baseline assessment; T1 = immediately after Session 1; T2 = 48 h after Session 1 (pre-Session 2); T3 = immediately after Session 2; T4 = 48 h after Session 2. Time effects were evaluated using repeated-measures analysis of variance (ANOVA).

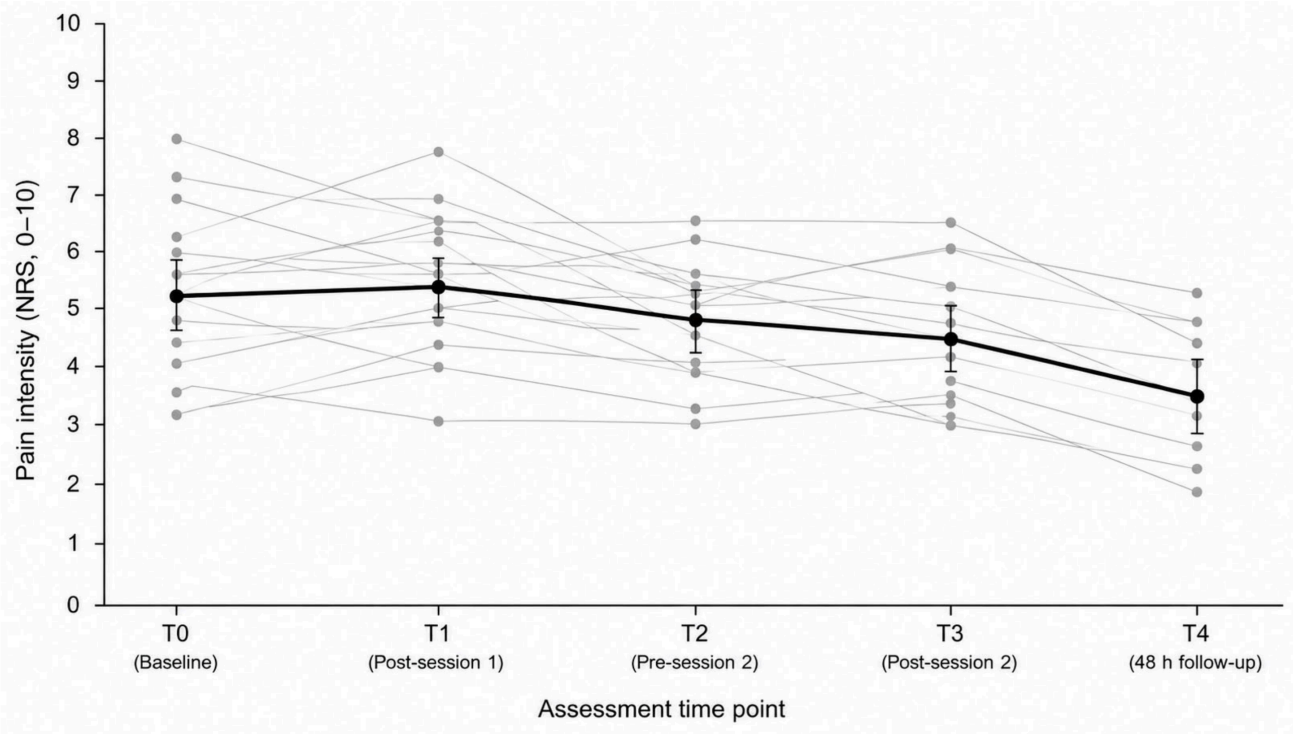


Figure 2. Pain intensity across repeated assessments (T0–T4). Gray lines represent individual participant trajectories, whereas black circles and lines represent group mean values. Error bars indicate 95% confidence intervals. Statistical analyses are presented in Table 4.

3.5. Pressure Pain Threshold

The pressure pain threshold demonstrated significant temporal changes in the splenius, upper trapezius, and temporalis regions, whereas no significant time effect was observed for the masseter. Detailed repeated-measures ANOVA results are presented in Table 5. Holm-adjusted pairwise comparisons identified significantly higher PPT values in the splenius at T4 compared with T1 (adjusted $p = 0.007$) and T3 (adjusted $p = 0.042$). No other pairwise comparisons remained statistically significant after Holm adjustment. Complete descriptive data and repeated-measures ANOVA results are presented in Table 5, whereas temporal trajectories are illustrated in Figure 3.

Table 5. Pressure pain threshold across repeated assessments according to anatomical region.

Anatomical Region	T0	T1	T2	T3	T4	Repeated-Measures ANOVA		
						***F* (df)**	***p*-Value**	**ηp^2**
Splenius	1.03 ± 0.73	1.00 ± 0.85	1.13 ± 0.84	1.13 ± 0.73	1.39 ± 0.77	F (4,56) = 6.64	<0.001	0.322
Upper trapezius †	1.38 ± 1.23	1.42 ± 1.32	1.49 ± 1.11	1.45 ± 1.11	1.73 ± 1.26	F (2.22,31.04) = 4.65	0.015	0.249
Masseter †	0.75 ± 0.55	0.84 ± 0.75	0.90 ± 0.76	0.95 ± 0.70	0.99 ± 0.75	F (2.04,28.62) = 1.94	0.162	0.122
Temporalis	1.12 ± 0.85	1.24 ± 0.86	1.27 ± 0.88	1.25 ± 0.78	1.35 ± 0.84	F (4,56) = 3.90	0.007	0.218

Abbreviations: PPT = pressure pain threshold; SD = standard deviation; ηp^2, partial eta squared. **Note:** Data are presented as mean ± standard deviation and expressed in kg/cm^2. T0 = baseline assessment; T1 = immediately after Session 1; T2 = 48 h after Session 1 (pre-Session 2); T3 = immediately after Session 2; T4 = 48 h after Session 2. Time effects were evaluated using repeated-measures analysis of variance (ANOVA). † Greenhouse–Geisser-corrected degrees of freedom and *p*-values are reported when the assumption of sphericity was violated.

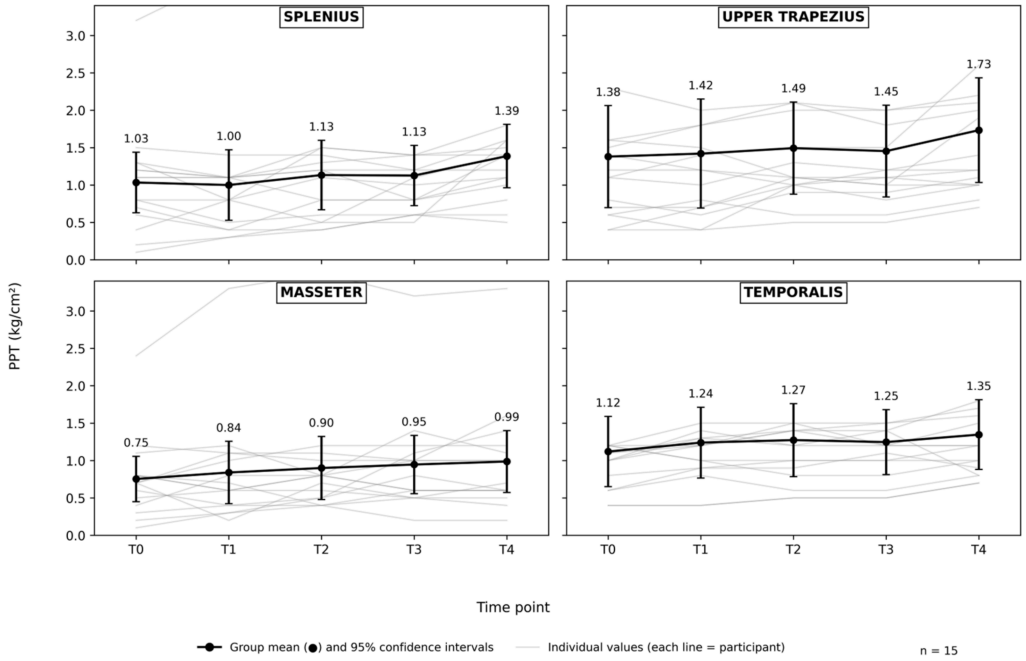


Figure 3. Pressure pain threshold (PPT) across repeated assessments according to anatomical region. Gray lines represent individual participant trajectories, whereas black circles and lines represent group mean values. Error bars indicate 95% confidence intervals. PPT values are expressed in kg/cm^2. Statistical analyses are presented in Table 5. T0 = baseline assessment; T1 = immediately after Session 1; T2 = 48 h after Session 1 (pre-Session 2); T3 = immediately after Session 2; T4 = 48 h after Session 2.

4. Discussion

This pilot longitudinal study showed that a relaxation-oriented immersive virtual reality intervention was feasible and well tolerated in adults with bruxism-related orofacial pain, achieving complete intervention adherence without serious adverse events. Exploratory findings also suggested progressive reductions in pain intensity together with modest increases in the pressure pain threshold during follow-up, particularly at the final assessment (T4). Although these findings should be interpreted cautiously because of the pilot design, small sample size, and absence of a control group, they provide preliminary observations that support the rationale for evaluating immersive virtual reality interventions in future controlled studies.

The intervention protocol achieved complete adherence, with all participants completing both immersive virtual reality sessions and all scheduled assessments without serious adverse events. In addition, cybersickness symptoms remained mild throughout the study, supporting the feasibility of implementing the intervention in this pilot population. These findings are consistent with previous immersive virtual reality studies in individuals with fibromyalgia and chronic musculoskeletal pain, which have similarly reported high adherence rates and good tolerability under supervised intervention protocols [32–35]. Collectively, these findings support the feasibility of immersive virtual reality as a complementary rehabilitation strategy for individuals with persistent pain conditions.

Participants also reported high levels of perceived presence during the immersive virtual reality sessions, reflected by elevated IPQ scores. A strong sense of presence has been proposed as a key component of immersive virtual reality interventions because it may enhance user engagement and facilitate temporary attentional disengagement from pain-related stimuli [15,16,36]. Although the present study was not designed to investigate underlying mechanisms, the combination of high perceived presence and low cybersickness symptoms suggests that the intervention provided an immersive experience that was well tolerated and suitable for repeated administration in this pilot population.

Pain intensity decreased progressively throughout follow-up, with the greatest reduction observed 48 h after the second immersive virtual reality session (T4) rather than immediately after the intervention sessions. This temporal pattern suggests that the effects of the intervention may develop gradually following repeated exposure, instead of producing an immediate analgesic response. Similar delayed improvements have been described following relaxation-based and mindfulness-oriented interventions, in which symptom reduction may emerge progressively as attentional regulation and behavioral adaptation are reinforced over repeated sessions [13,37,38]. Although the present study was not designed to investigate the mechanisms underlying pain modulation, these findings support the rationale for evaluating repeated immersive virtual reality sessions in future controlled studies. Because this pilot study was not designed or powered to establish clinical efficacy, the observed reduction in pain intensity should be interpreted as preliminary, and future randomized controlled trials should determine whether these changes achieve clinically meaningful improvements. Although the observed reduction from baseline to the final follow-up (1.67 points; approximately 32%) approximated previously proposed thresholds for a minimal clinically important difference on the Numeric Rating Scale [39], this observation should be interpreted cautiously because of the exploratory, uncontrolled design of the present study.

The relaxation-oriented characteristics of the intervention may also have contributed to the observed responses. Bruxism-related pain is frequently associated with stress, sustained muscular tension, and increased vigilance toward painful stimuli. Consequently, immersive environments designed to promote relaxation and attentional disengagement from pain may offer a promising complementary strategy for individuals presenting persistent muscular tension and psychoemotional burden [40,41]. In addition, immersive audiovisual stimulation together with mindfulness-related elements may facilitate temporary reductions in pain-related attention and muscular guarding, potentially contributing to short-term symptom modulation [42].

The pressure pain threshold demonstrated significant temporal changes in the splenius, upper trapezius, and temporalis regions, whereas no significant overall time effect was observed for the masseter. Nevertheless, after adjustment for multiple comparisons, significant pairwise differences were limited to the splenius, with higher values at T4 than at T1 and T3. These findings suggest that pressure pain sensitivity may have varied over time, although the absence of a control group, the small sample size, and the limited number of significant pairwise comparisons preclude attributing these changes directly to the intervention. Similar sensory responses have been described following relaxation-based interventions and immersive virtual reality applications in chronic pain populations [43,44]. Because the present study did not directly investigate the physiological mechanisms underlying these responses, any mechanistic interpretation should be considered hypothetical.

The present findings should also be interpreted within the context of several limitations. First, the study included a small convenience sample and lacked a control group, limiting the ability to establish causal relationships or generalize findings to broader populations. Consequently, the observed reductions in pain intensity and changes in the pressure pain threshold should be considered preliminary and exploratory, as alternative explanations such as natural symptom fluctuation, regression to the mean, expectancy effects, and contextual effects cannot be excluded. Second, the follow-up period was limited to 48 h after the second intervention session, preventing any conclusions regarding the durability or long-term sustainability of the observed responses. Third, the sample consisted predominantly of women (93.3%), which may limit the external validity and generalizability of the findings to male populations with bruxism-related orofacial pain. Future studies

should include more balanced samples to determine whether the feasibility, tolerability, and exploratory clinical responses observed in this study are consistent across sexes. In addition, psychological variables such as anxiety, perceived stress, sleep quality, and catastrophizing were not formally evaluated despite their recognized relationship with bruxism and pain modulation. Future controlled studies should incorporate validated instruments assessing these domains, such as the Generalized Anxiety Disorder-7 (GAD-7), Perceived Stress Scale (PSS), and Pittsburgh Sleep Quality Index (PSQI), to provide a more comprehensive understanding of the mechanisms underlying clinical responses. Furthermore, bruxism classification was based on self-reported symptoms using the CAB questionnaire, consistent with the classification of possible bruxism, and therefore should not be interpreted as a definitive clinical diagnosis. Finally, because this was a pilot feasibility study, inferential analyses should be interpreted as exploratory and hypothesis-generating rather than confirmatory.

Despite its exploratory nature, this study supports the feasibility and tolerability of immersive virtual reality interventions in individuals with bruxism-related orofacial pain. The observed temporal changes in pain intensity and the pressure pain threshold should be considered exploratory and hypothesis-generating, supporting the rationale for future controlled trials incorporating larger samples, longer follow-up periods, and multidimensional outcomes.

5. Conclusions

This pilot longitudinal study showed that an immersive virtual reality intervention was feasible and well tolerated in adults with bruxism-related orofacial pain, with high adherence rates and low levels of cybersickness-related symptoms. Participants also reported high levels of immersive engagement throughout the intervention sessions.

Preliminary findings suggested progressive reductions in pain intensity and modest increases in the pressure pain threshold during follow-up assessments, particularly after repeated immersive exposure. Although these findings should be interpreted cautiously because of the exploratory nature of the study and the absence of a control group, they support further investigation of relaxation-oriented immersive virtual reality as a complementary rehabilitation strategy for individuals with bruxism-related orofacial pain.

Future controlled studies incorporating larger samples, longer follow-up periods, and multidimensional clinical and psychoemotional outcomes are warranted to clarify the clinical effects and therapeutic role of immersive virtual reality in individuals with bruxism-related orofacial pain.

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Abbreviations

The following abbreviations are used in this manuscript:

IVR	Immersive Virtual Reality
PPT	Pressure pain threshold
IPQ	Igroup Presence Questionnaire
SSQ	Simulator Sickness Questionnaire
NRS	Numeric Rating Scale

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